

Mixing of Water in Streams: Big Walnut Creek and its Tributaries, Ohio¹

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ABSTRACT. A graphical procedure for resolving three-component mixtures of water is demonstrated by using chemical analyses of Big Walnut Creek and two of its tributaries (Alum Creek and Blacklick Creek) near Columbus, OH. The concentrations of conservative cations (Na, Ca, Mg, and Sr) indicate that on 5 December 1992 Alum Creek contributed $46.6 \pm 0.6\%$, whereas Blacklick Creek added $28.2 \pm 2.0\%$ of the water in Big Walnut Creek downstream of the confluence. The procedure can be used in laboratory exercises to provide rational explanations for variations in the chemical compositions of streams and to gain insight into the different types of water that may mix in a stream.

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INTRODUCTION

Mixing is an important phenomenon in nature that may affect the chemical compositions of water as well as of sedimentary and volcanic rocks. For example, mixing takes place at the confluences of streams and may cause changes in the concentrations of the major conservative ions in the water, such as: Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Sr^{2+} , SO_4^{2-} , and Cl^- . The concentrations of these ions in the mixed water depend on the chemical compositions of the waters in the streams and on the proportions in which they are mixed. The equations that govern the concentrations of conservative ions in two-component mixtures were presented by Faure (1991) and can be used to model the effect of mixing on the chemical compositions of streams.

In this paper, we consider the effect of mixing water from three sources on the chemical composition of a stream in order to demonstrate a graphical procedure that is suitable for use in laboratory exercises in the context of environmental geochemistry courses. The demonstration is based on a small set of water samples collected from Big Walnut Creek and its tributaries in Columbus, OH. This stream was chosen because its two principal tributaries (Blacklick Creek and Alum Creek) enter Big Walnut Creek from opposite directions but at the same place. Therefore, the chemical composition of water in Big Walnut Creek downstream of the confluence with its two tributaries is a mixture of water derived from three sources.

MATERIALS AND METHODS

The water samples were collected on 5 December 1992 along the course of Big Walnut Creek and its two tributaries at sites indicated in Figure 1. Samples of surface water were collected from bridges and were stored in pre-cleaned 500 mL polyethylene bottles. The samples were filtered through $0.45 \mu\text{m}$ filters (Millipore Corp.) under vacuum and acidified to a pH of about 2

by the addition of two drops of concentrated reagent-grade nitric acid.

The filtered and acidified samples were analyzed by Inductively Coupled Plasma Spectrometry (ICP) in the Department of Geological Sciences at The Ohio State University. The elements included in the analyses were Na, Mg, Ca, and Sr, all of which are considered to be conservative because their concentrations are not affected by chemical reactions, ion exchange processes, or biological activity in Big Walnut Creek. Each sample was analyzed in triplicate and the resulting average concentrations are listed (Table 1). The results of the triplicate analyses of each sample were used to estimate the reproducibility of the analytical results. The resulting average analytical precision errors are: ± 0.30 ppm for Ca^{2+} ; ± 0.40 ppm for Na^+ ; ± 0.41 for Mg^{2+} , and ± 0.02 ppm for Sr^{2+} (Petz 1992).

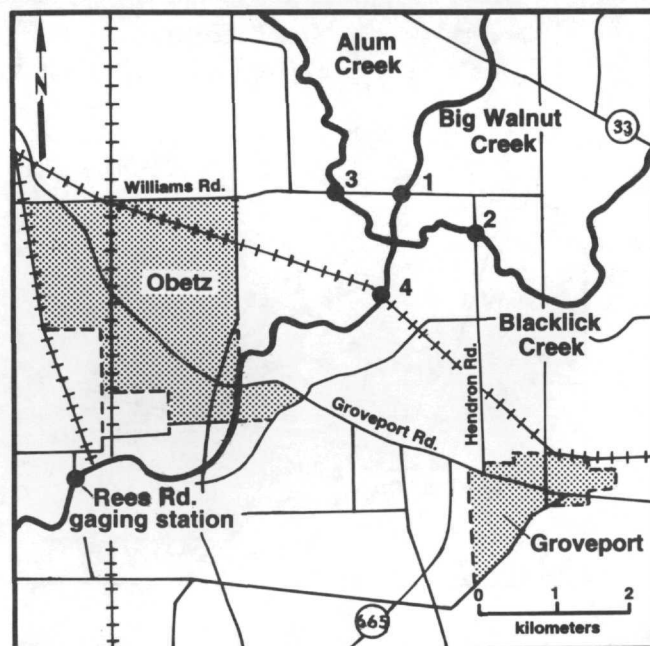


FIGURE 1. Confluence of Big Walnut Creek with Alum Creek and Blacklick Creek south of the city limit of Columbus, OH. The collecting sites of water samples (1 through 4) as well as the gaging station on Big Walnut Creek at Rees Road are identified.

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TABLE 1

Concentrations of conservative cations in Big Walnut Creek and its tributaries (mg/L). The collecting sites are identified by number in Figure 1.

Sample number	Stream*	Na	Mg	Ca	Sr
1	BWC	30.4	22.3	74.7	0.41
2	BC	49.5	25.4	87.2	0.48
3	AC	25.7	21.1	72.5	0.69
4	BWC	33.1	22.7	77.3	0.56

*BWC = Big Walnut Creek; BC = Blacklick Creek; AC = Alum Creek

Demonstration of Three-Component Mixing

The concentrations of Na and Sr of water in Big Walnut Creek (1), Blacklick Creek (2), and Alum Creek (3) define three points labeled 1, 2, and 3 in Figure 2. A straight line connecting point 1 (Big Walnut Creek) to point 2 (Blacklick Creek) is the locus of all points that represent mixtures of water of these two streams (Faure 1991). Similarly, straight lines connecting sample 2 to 3 and sample 3 to 1 represent mixtures of Blacklick Creek and Alum Creek and of Alum Creek and Big Walnut Creek, respectively. In this way, the waters of the three streams define a triangle of mixing in coordinates of the concentrations of Na and Sr. Sample 4, collected downstream of the triple confluence on Big Walnut Creek, plots within the mixing triangle in Figure 2, thereby confirming the expectation that it is a mixture of water derived from the three sources.

The composition of the mixed water (4) in Big Walnut Creek can be determined graphically by the procedure outlined below. The abundance of water from Alum Creek in sample 4 is determined by drawing a

straight line (AC) at right angles to the mixing line of samples 1 and 2 through sample 4 as shown in Figure 2. In addition, a straight line parallel to the mixing line of samples 1 and 2 is drawn through sample 3. The concentration of Alum Creek water in sample 4 is equal to the ratio of the line segments AB and AC. The length of the line segment AB is 27.5 centimeters (cm) and that of line segment AC is 59.0 cm. Therefore, the concentration of Alum Creek water (S3) in sample 4 is:

$$S3 = \frac{AB}{AC} = \frac{27.5}{59.0} = 0.466 \text{ or } 46.6\%$$

Similarly, the concentration of Blacklick water (S2) in sample 4 is the ratio of line segments measured along the line DE which was constructed in the same way as line AC. Therefore:

$$S2 = \frac{DB}{DE} = \frac{20.0}{76.5} = 0.261 \text{ or } 26.1\%$$

The concentration of Black Walnut water (S1) in sample 4 can be determined by repeating the procedure a third time. However, the concentration of Black Walnut water in sample 4 can also be determined algebraically from the requirement that:

$$\begin{aligned} S1 + S2 + S3 &= 1.00. \\ \text{Since } S2 &= 0.261 \text{ and } S3 = 0.466, \\ S1 + 0.261 + 0.466 &= 1.00. \end{aligned}$$

Therefore, the concentration of Blacklick water (S1) in sample S4 is 27.3%.

Additional estimates of the concentration of water derived from the three sources in sample 4 can be derived from mixing triangles obtained by plotting the concentrations of Sr versus Ca and Mg. The resulting estimates of the concentrations of tributary waters in sample 4 are listed in Table 2. The numerical values of the concentrations of the three types of water in sample 4 are similar but not identical. Since the results obtained from each of the three mixing triangles have an equal probability of being correct, the three sets of estimates were averaged and the dispersion of the data was expressed as one standard deviation.

The results in Table 2 indicate that on 5 December 1992 Alum Creek contributed $46.6 \pm 0.6\%$ of the water in sample 4 of Big Walnut Creek. The abundance of Blacklick water was approximately equal to the abundance of water derived from the Big Walnut Creek itself (for example, Blacklick: $28.2 \pm 2.0\%$ and Big Walnut: $25.8 \pm 1.4\%$).

The concentrations of waters derived from different sources in sample 4 can be used to calculate the discharges in each of the three branches of Big Walnut Creek. The discharge of Big Walnut Creek on 5 December 1992 at the Rees Road gaging station (#03229500; Fig. 1) was 156 cubic feet/second or $4.42 \text{ m}^3/\text{s}$ (Shindel and others 1993). Therefore, the data in Table 2 yield a discharge of $0.466 \times 156 = 72.7 \text{ ft}^3/\text{s}$ ($2.03 \text{ m}^3/\text{s}$) for Alum Creek, $44.0 \text{ ft}^3/\text{s}$ ($1.25 \text{ m}^3/\text{s}$) for Blacklick Creek, and

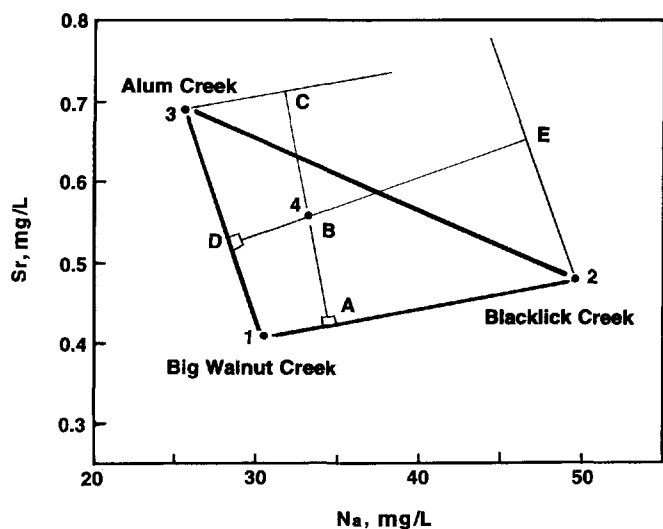


FIGURE 2. Mixing triangle based on the concentrations of Na and Sr in waters of the 3 branches of Big Walnut Creek. The concentrations of the water derived from the 3 sources in sample 4 are determined by the graphical procedure explained in the text.

TABLE 2

Estimated concentrations of water from Alum Creek and Blacklick Creek in sample 4 downstream of the confluences of Big Walnut Creek with its tributaries, (%).

	AC	BC	BWC
Na-Sr	46.6	26.1	27.3
Ca-Sr	46.0	28.4	25.6
Mg-Sr	45.4	30.1	24.5
Average	46.0	28.2	25.8
	±0.6	±2.0	±1.4

AC = Alum Creek, BC = Blacklick Creek, and BWC = Big Walnut Creek upstream of the confluences (sample 1). The errors are one standard deviation defined as $s = (\sum(\bar{x}-x)^2/n-1)^{1/2}$, where x is a measurement, \bar{x} is the mean of those measurements, and n is the number of measurements.

40.2 ft³/s (1.14 m³/s) for Big Walnut Creek at the triple confluence.

Chemical Characteristics of Water

The data in Table 1 indicate that the water of Blacklick Creek has elevated concentrations of Na (49.5 mg/L), Mg (25.4 mg/L), and Ca (87.2 mg/L) compared to the water of Alum Creek which has low concentrations of these elements (Na = 25.7 mg/L; Mg = 21.2 mg/L; and Ca = 72.5 mg/L). However, Alum Creek water has a high Sr concentration (0.69 mg/L) compared to 0.48 mg/L in Blacklick Creek and only 0.41 mg/L in Big Walnut Creek.

These data therefore reveal the existence of three types of water in the drainage basin of Big Walnut Creek:

Type Stream	Concentrations			
	Na	Mg	Ca	Sr
I Blacklick	high	high	high	interm.
II Alum	low	low	low	high
III Big Walnut	interm.	interm.	interm.	low

Therefore, the concentrations of Na, Mg, and Ca in Big Walnut Creek are accountable by two-component mixing involving water types I and II whereas all three water types are required to account for the Sr concentration of sample 4 in Table 2.

Sets of water samples that formed by mixing water from only two sources are easy to recognize because the concentrations of conservative elements define straight lines in x-y coordinates (Faure 1991). If one of the two

sources of water is rainwater or snowmelt, the mixing line is directed toward the origin. In cases where the chemical compositions of the two water types are known, the lever rule can be used to determine the concentrations of the two water types in a given mixture from its position on the mixing line.

Sets of water samples that are mixtures of water derived from three or more sources form a cluster of points in x-y coordinates commonly referred to as a "shotgun pattern." Such patterns can be resolved into three components by the graphical procedure demonstrated here, provided the concentrations of conservative ions in the water derived from each source are known. Clustering of data points in x-y coordinates may also result from mixing of four or more types of water. However, such mixtures are not resolvable with presently available techniques.

Mixing of water in streams is not restricted to the confluences of tributaries like the one on Big Walnut Creek, but may occur in places where waters of different composition enter a stream or lake. Potential sources of chemically distinct water include not only tributaries, but also meteoric precipitation, groundwater derived from different bedrock aquifers, and industrial, municipal and agricultural waste water. The common occurrence of mixing in streams enhances the usefulness of the procedure demonstrated in this report.

CONCLUSIONS

The graphical interpretation of the concentrations of conservative cations demonstrated in this report has provided numerical estimates of the concentrations of water contributed by Alum Creek and Blacklick Creek to Big Walnut Creek at their confluence south of the city limits of Columbus. The results of this study demonstrate a procedure that may be used by practicing environmental geochemists and by students in laboratory exercises in environmental-science courses at the college or even high school level.

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